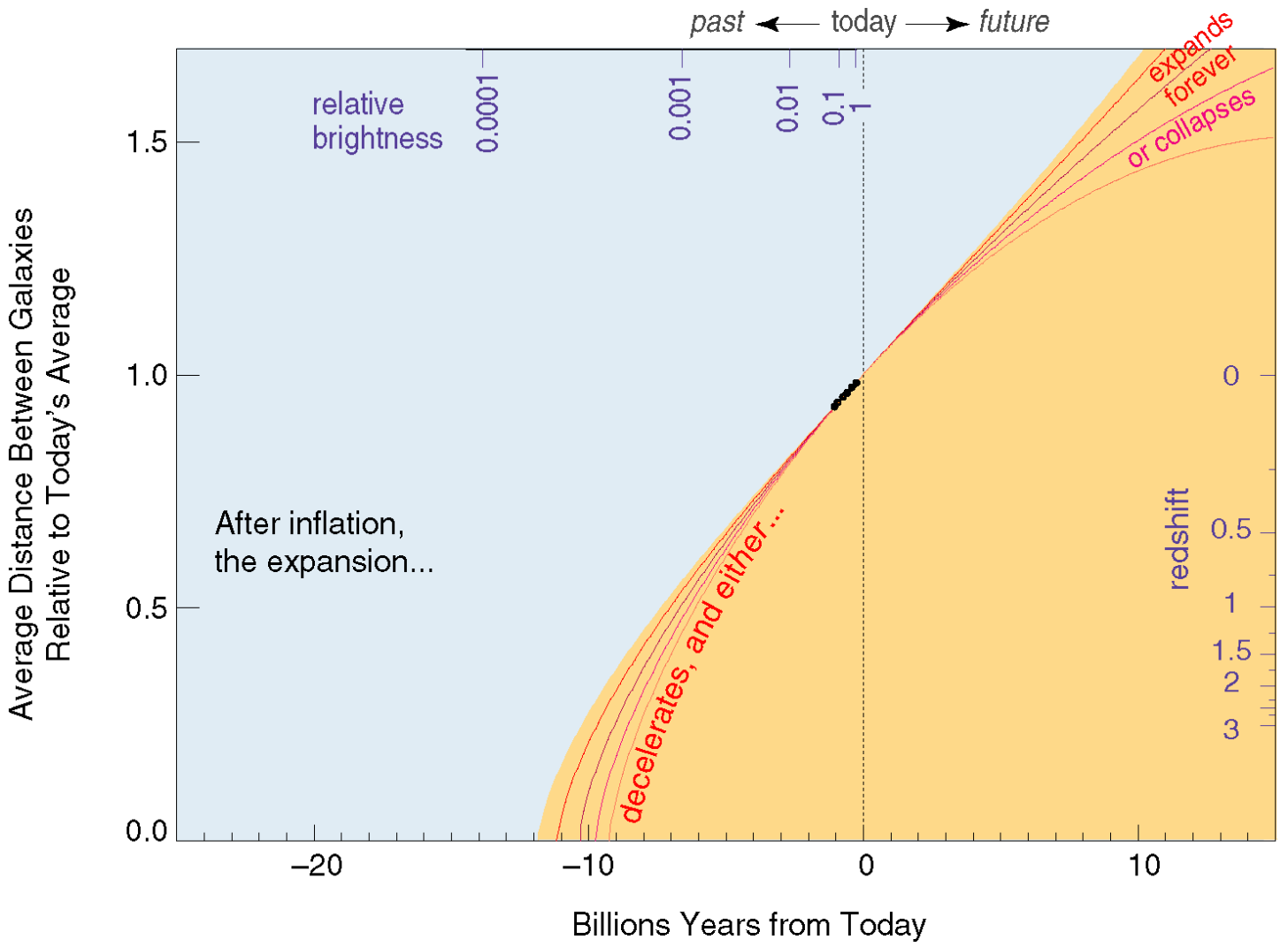
SNAP at Fermilab

The
Fermilab
Collaboration
in
SNAP

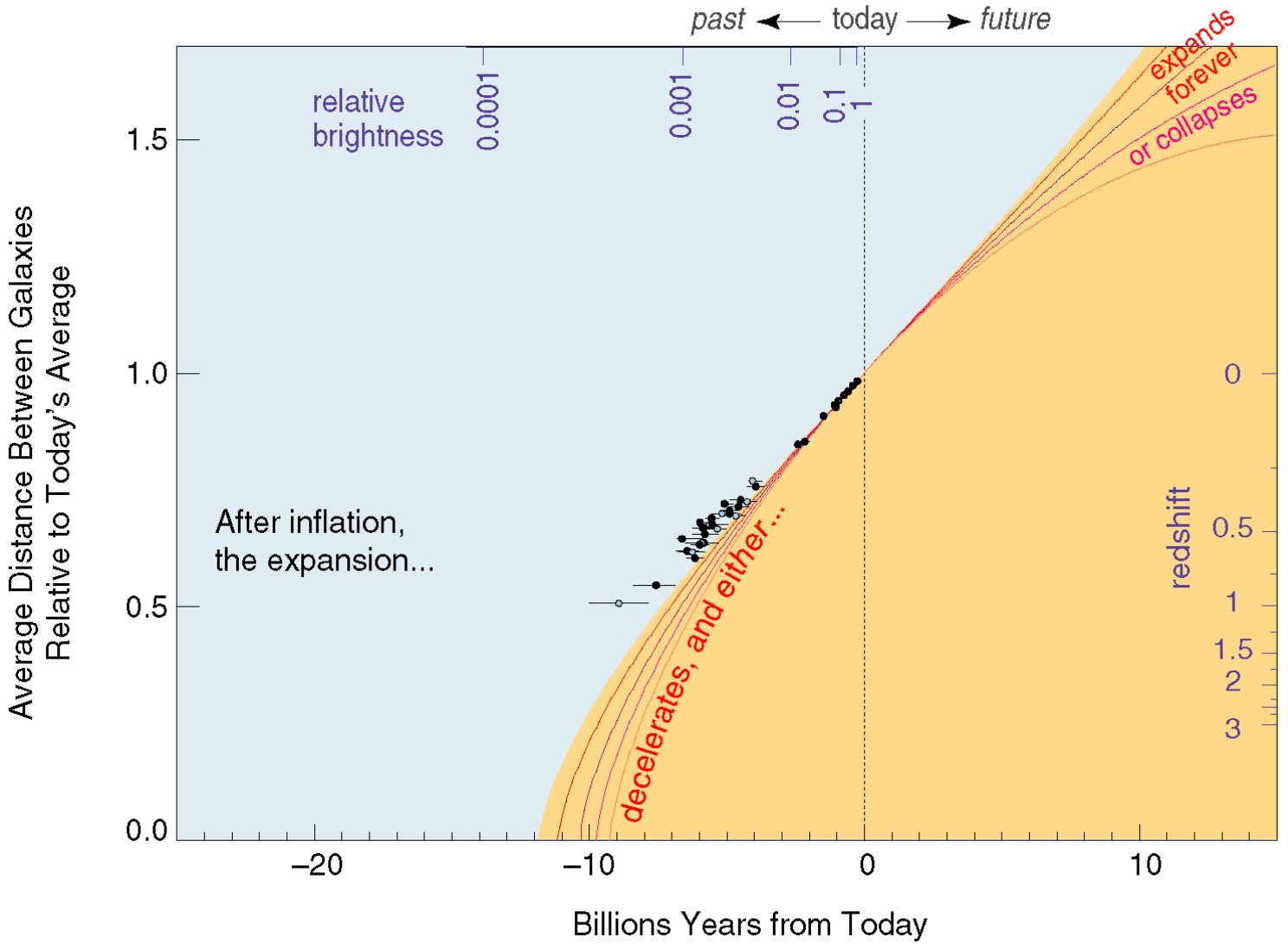
What is SNAP?

- **SNAP is a proposed space-based mission to probe the nature of dark energy and the accelerating universe.**
  - *A deep time-domain survey of Type Ia SNe, probably standard candles*
    - *Expect to see ~2000 SNe Ia in 2-3 yrs*
  - *A 300 sq. deg. wide-field survey for weak lensing, cluster counting & other science*
  - *Launch ~2010*
- **http://snap.lbl.gov**
- **SNAP is an important goal for DOE in this decade.**
  - *A DOE review has recommended it for CD-0 approval.*
  - *Centered at and managed from LBNL*
- **A dark-energy mission is on the NASA roadmap**
  - *A NASA Research Announcement (NRA) was made. Fermilab is part of responding teams.*
  - *We expect an announcement of a preliminary DOE/NASA agreement later this month.*

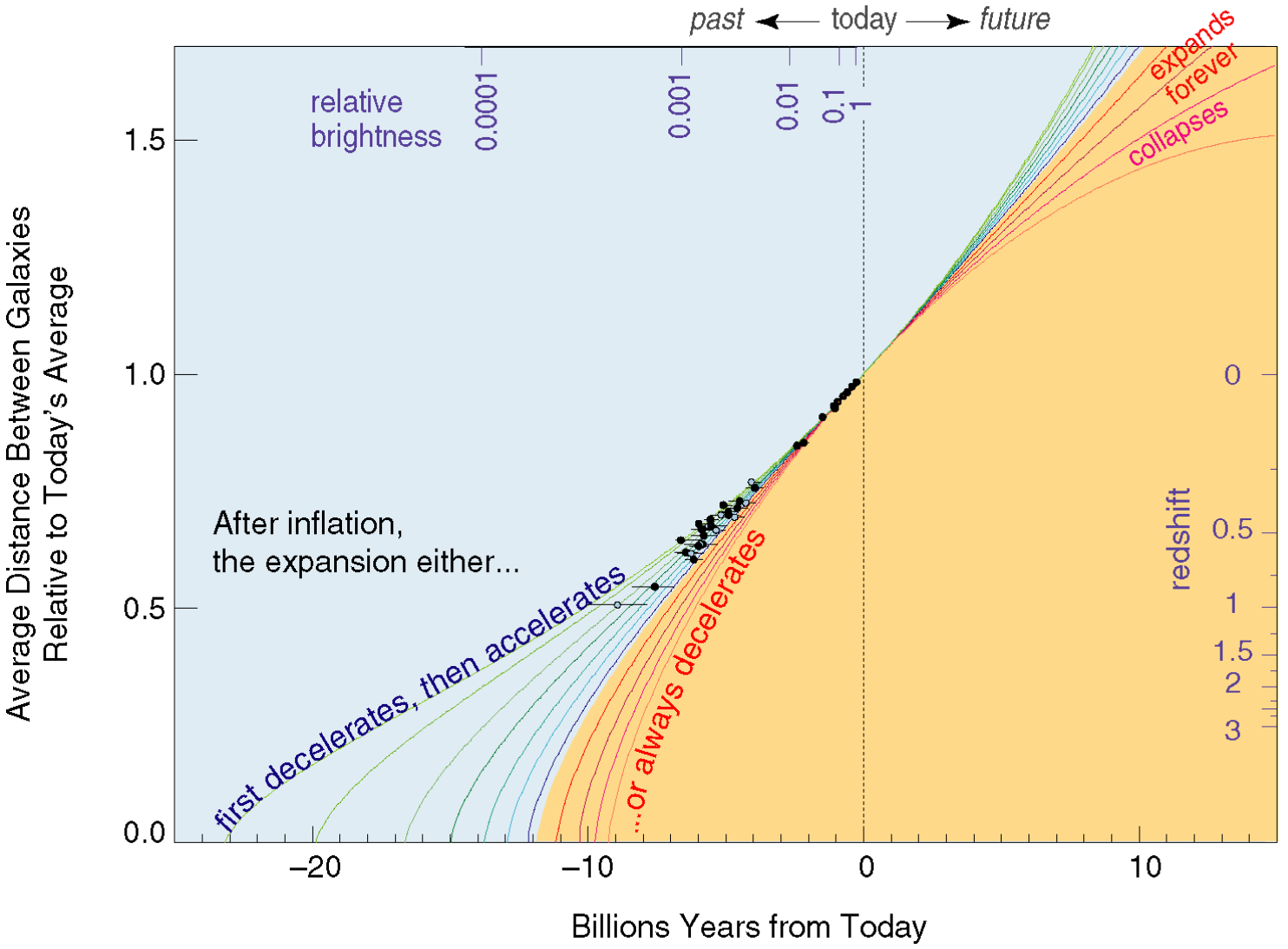
The Expansion History of the Universe



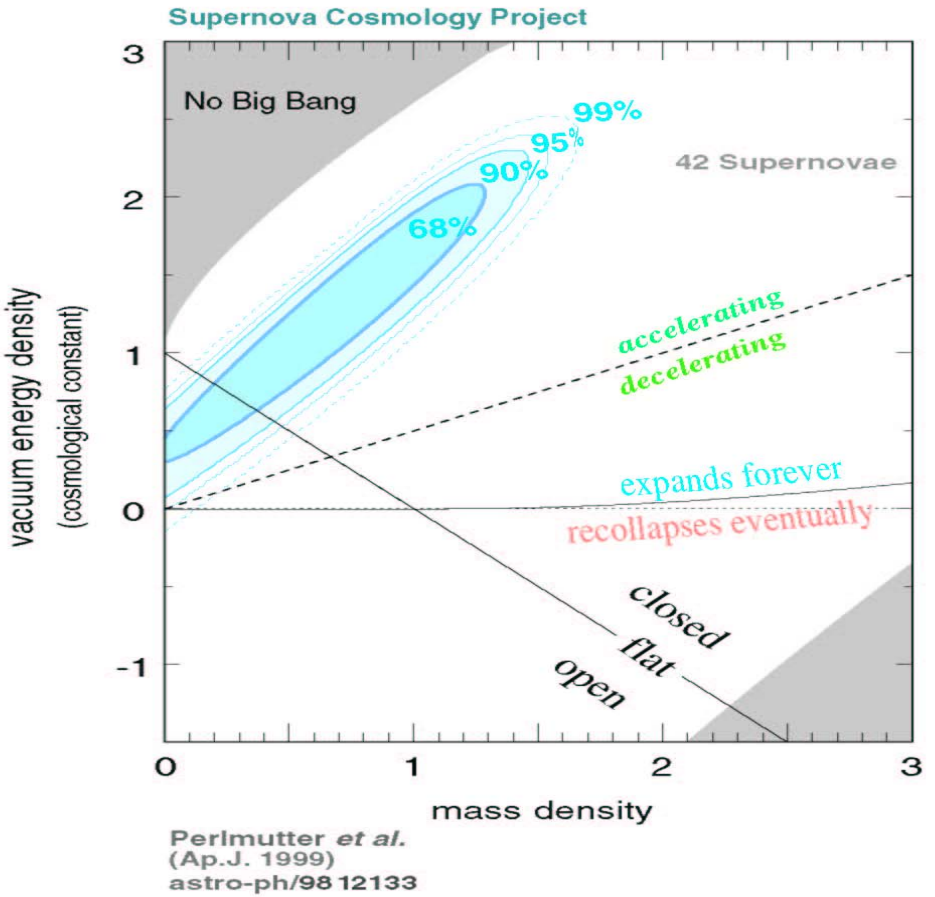
The Expansion History of the Universe



The Expansion History of the Universe



Replot Data in $\Omega_M - \Omega_\Lambda$ Space
Best-Fit Contours



What's wrong with a non-zero Λ?

- ***Why so small?***

  Might expect $\frac{\Lambda}{8\pi G} \sim m^4_{\text{Planck}}$

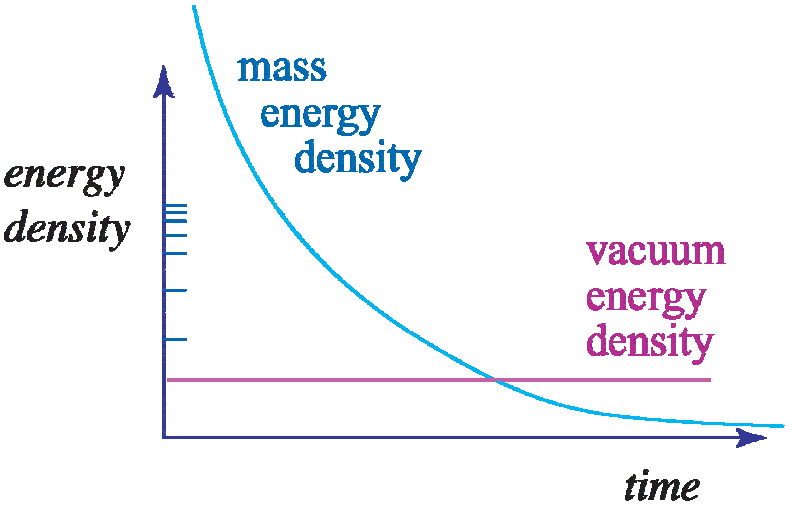
  This is off by ~120 orders of magnitude!

- ***"Why now?"***

$$\frac{\ddot{R}}{R} = -\frac{4\pi G}{3}(\rho + 3p)$$

MATTER: $p = 0 \rightarrow \rho \propto R^{-3}$

VACUUM ENERGY: $p = -\rho \rightarrow \rho \propto constant$



What's wrong with a non-zero Λ?

- ***Why so small?***

  Might expect $\frac{\Lambda}{8\pi G} \sim m^4_{\text{Planck}}$

  This is off by ~120 orders of magnitude!

What are the alternatives?

- ***"Why now?"***

$$\frac{\ddot{R}}{R} = -\frac{4\pi G}{3}(\rho + 3p)$$

MATTER: $p = 0 \rightarrow \rho \propto R^{-3}$

VACUUM ENERGY: $p = -\rho \rightarrow \rho \propto constant$

New Physics: "Dark energy":
Dynamical scalar fields, "quintessence",...

General
Equation of State:

$$p = w\rho \rightarrow \rho \propto R^{-3(1+w)}$$

and w can vary with time

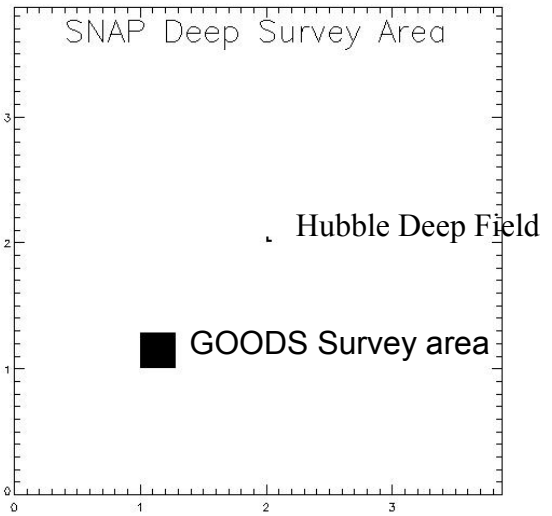
What makes SNAP unique?

- **It views from space**
  - — **Can see further into the NIR**
  - — **Can see further back in time**
  - — **Eliminates many atmospheric & earthbound problems**
    - ***temperature fluctuations, turbulence, etc.***

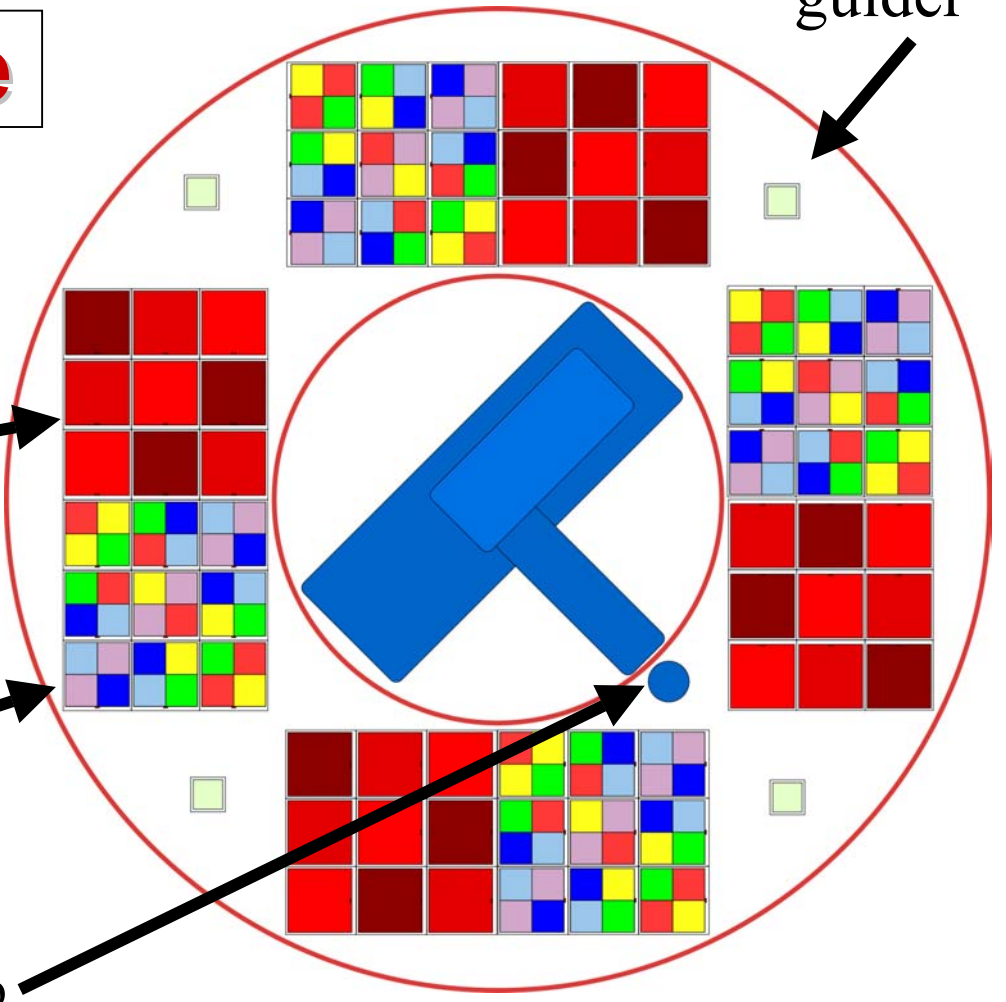
- **It has a wide field of view**
  - — **Appropriate for a large-field survey**

- **It has good spatial resolution**
  - — **Small pixels, smallpoint-spread-function (PSF)**

- **It has many optical and NIR filters**
  - — **Accurate photometric redshifts**



SNAP Focal Plane



Detector -covered field of view is 0.7 square degrees

140 million infrared pixels
3 NIR filters (1-1.7μm) on 4 HgCdTe detector banks

440 million optical pixels
0.1 by 0.1 arcseconds
6 optical (350-1000 nm) filters

Spectrograph for SN followup

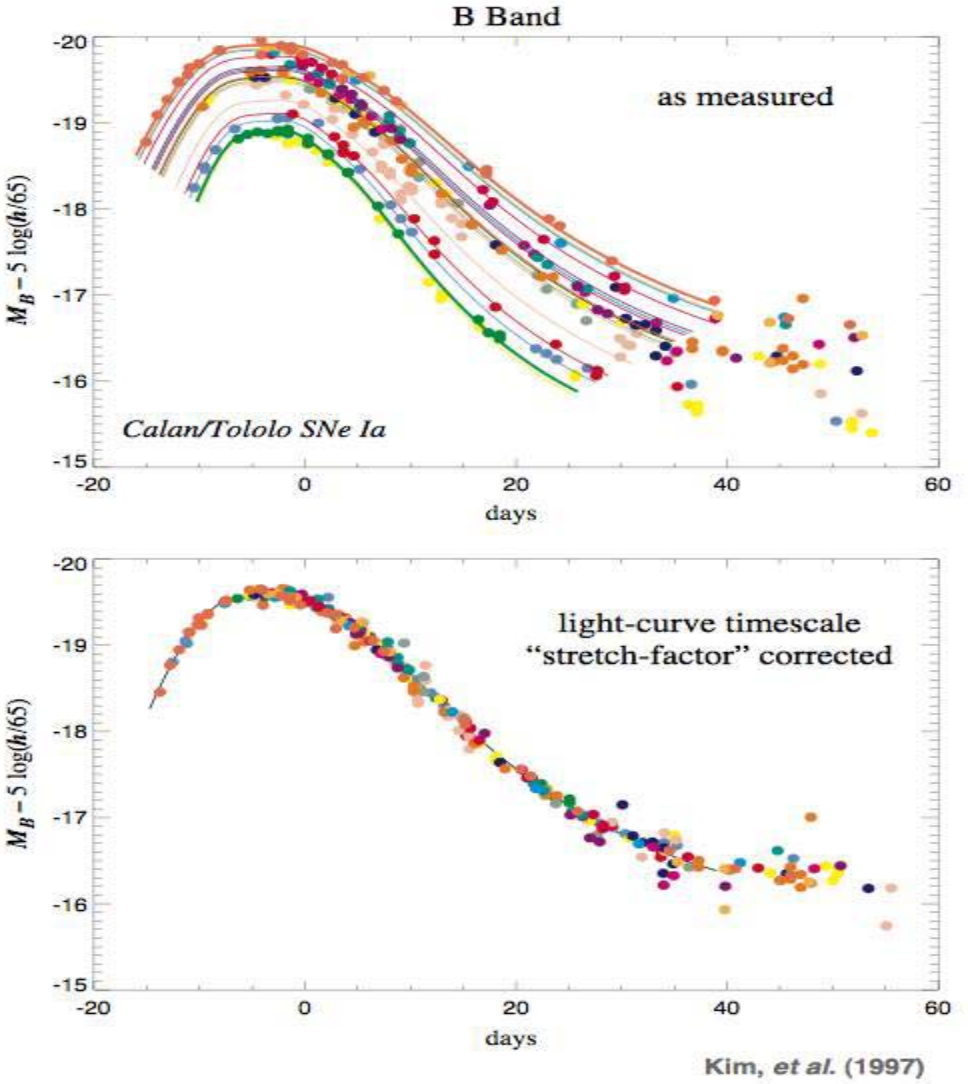
~100 GB of data per day, downloads every 3 days

How do the surveys work?

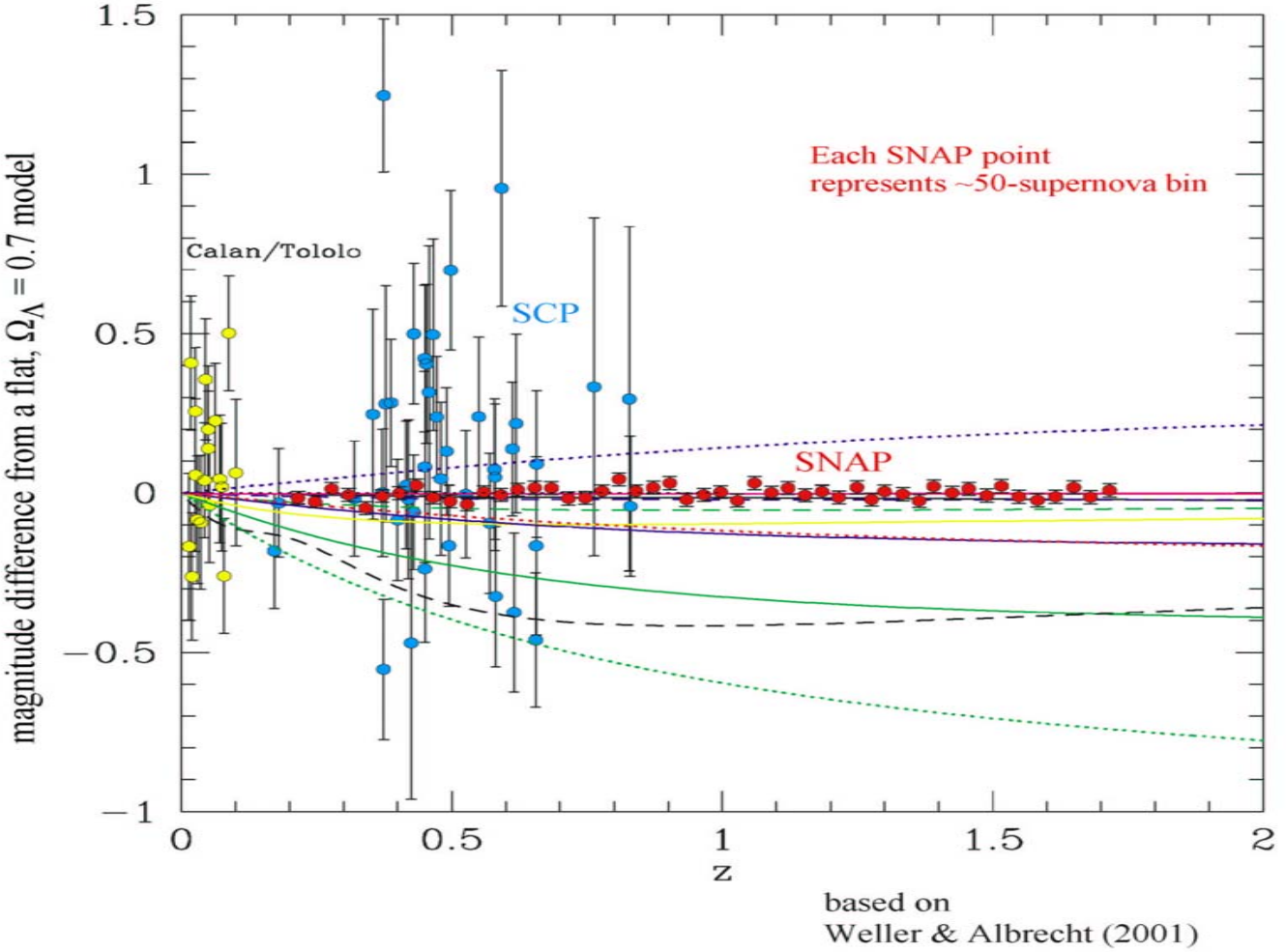
SNe Ia are distinguished by being a (probable) standardizable candle and by having unique spectrographic and time-development fingerprints.

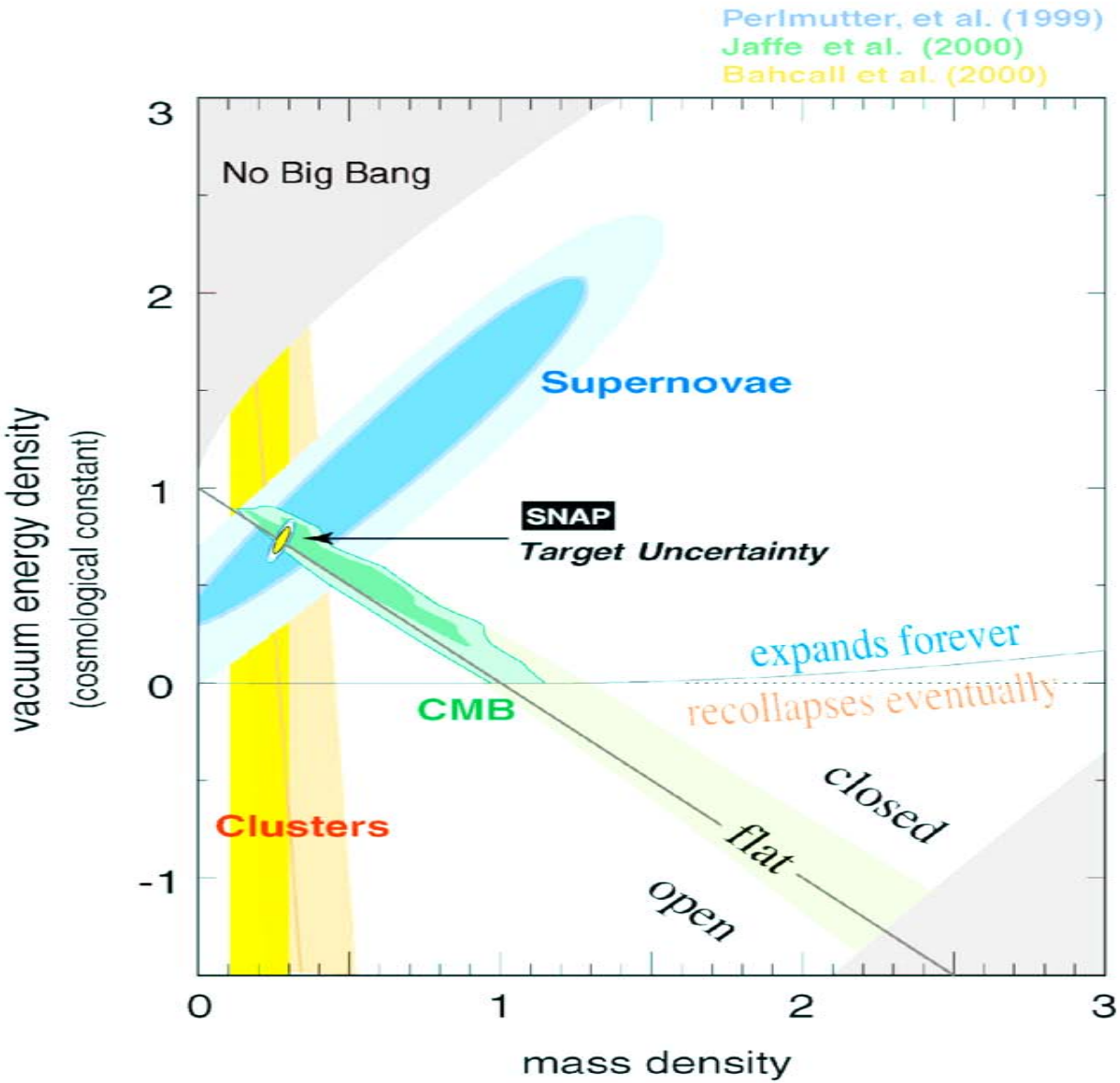
1. ***Repetitively scan a two 7.5 sq. deg. pieces of the sky, one in the north, one south. Each scan takes about 3 days with the wide-field camera.***
   a. The camera has about 5E8 pixels and nine color filters from visible into near IR.
2. ***Subtract each scan from a reference scan to look for SNe.***
3. ***Use the camera with filters to "trigger" on SNe Ia. Follow progress with the camera to obtain the light curve.***
4. ***Use a spectrograph to obtain the redshift of interesting SNe during peak brightness.***
   a. This information also helps to identify type Ia SNe.
5. ***The two deep surveys take ~3 yrs of an ~4-year mission to get ~2000 SNe.***
   a. The rest of the time is used for the wide-field survey and "guest observations."
6. ***All the data are stored in on-board memory and are transmitted down on every orbit at the perigee, every three days.***
7. ***The wide-field survey is a single-pass look at a broad field for weak-lensing, cluster counting, etc.***
   a. The wide-field survey is limited by data rate, so there may have to be more memory and more telemetry bandwidth, or more compression.

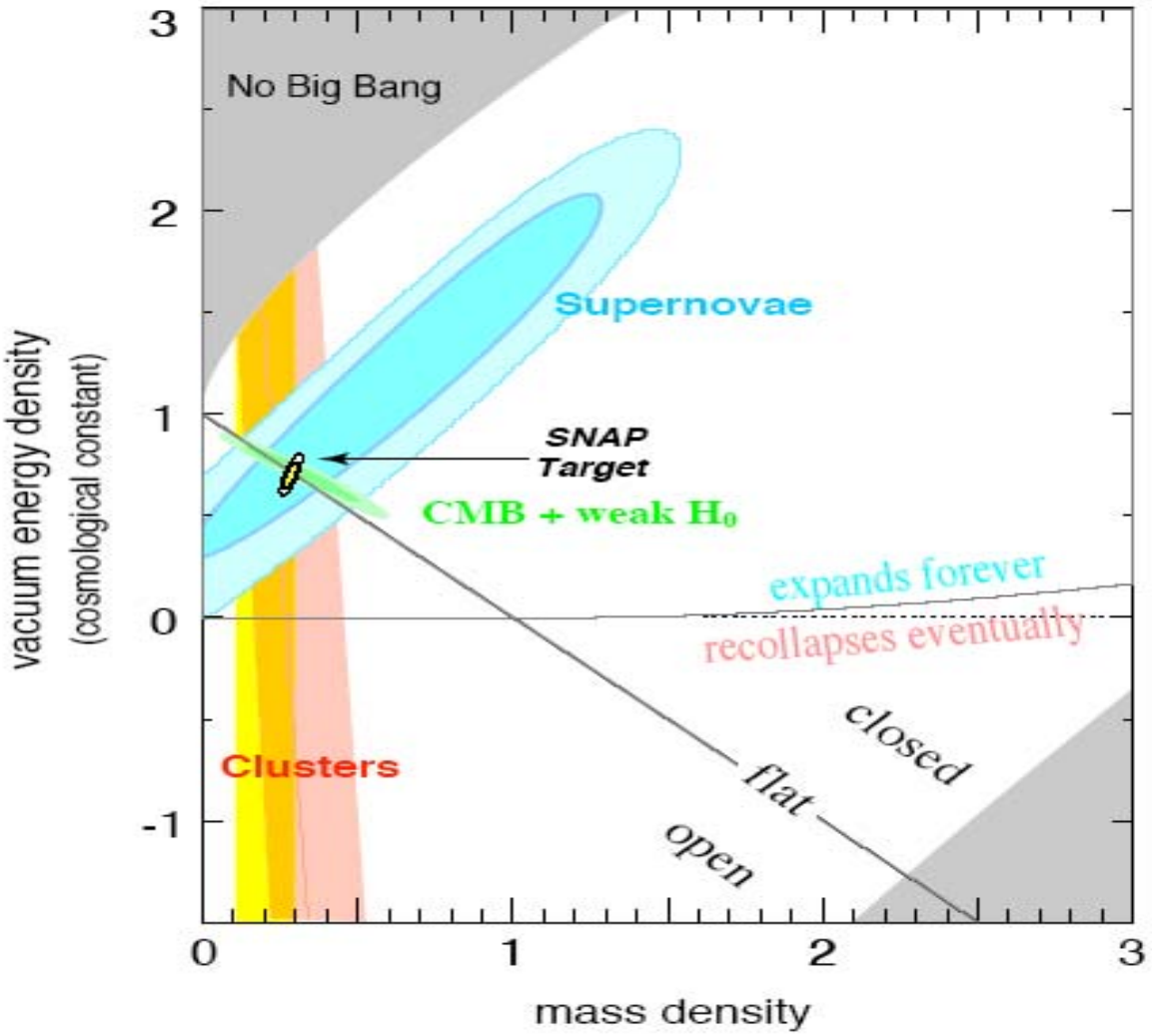
Type Ia Supernovae - A Standard(izable) Candle



Current ground-based data
compared with binned simulated SNAP data
and a sample of Dark Energy models.




Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall et al. (2000)
No Big Bang
Supernovae
SNAP
Target Uncertainty
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


No Big Bang
Supernovae
SNAP
Target
CMB + weak H₀
expands forever
recollapses eventually
closed
flat
open
Clusters
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3

Other Methods to Probe Dark Energy

- Weak Lensing
- Cluster Counting
- ?

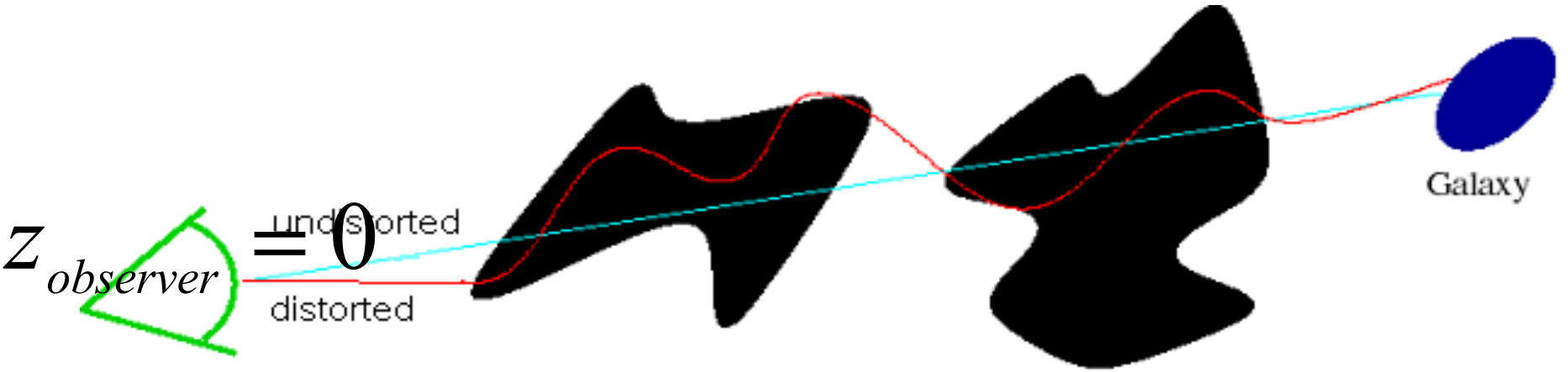
Other Science Using the SNAP Platform

The depth, spatial resolution, many color filters and wide field make SNAP uniquely powerful for imaging surveys.

- Evolution of galaxies
- Quasars
- Gamma-ray burst afterglows
- Reionization history
- Transients
- Faint stars
- Solar-system objects
- Strong lensing

Weak Gravitational Lensing

In the absence of large-scale structure, light beams from a galaxy follow the undistorted path. Dark matter bends space and the light follows the distorted path.



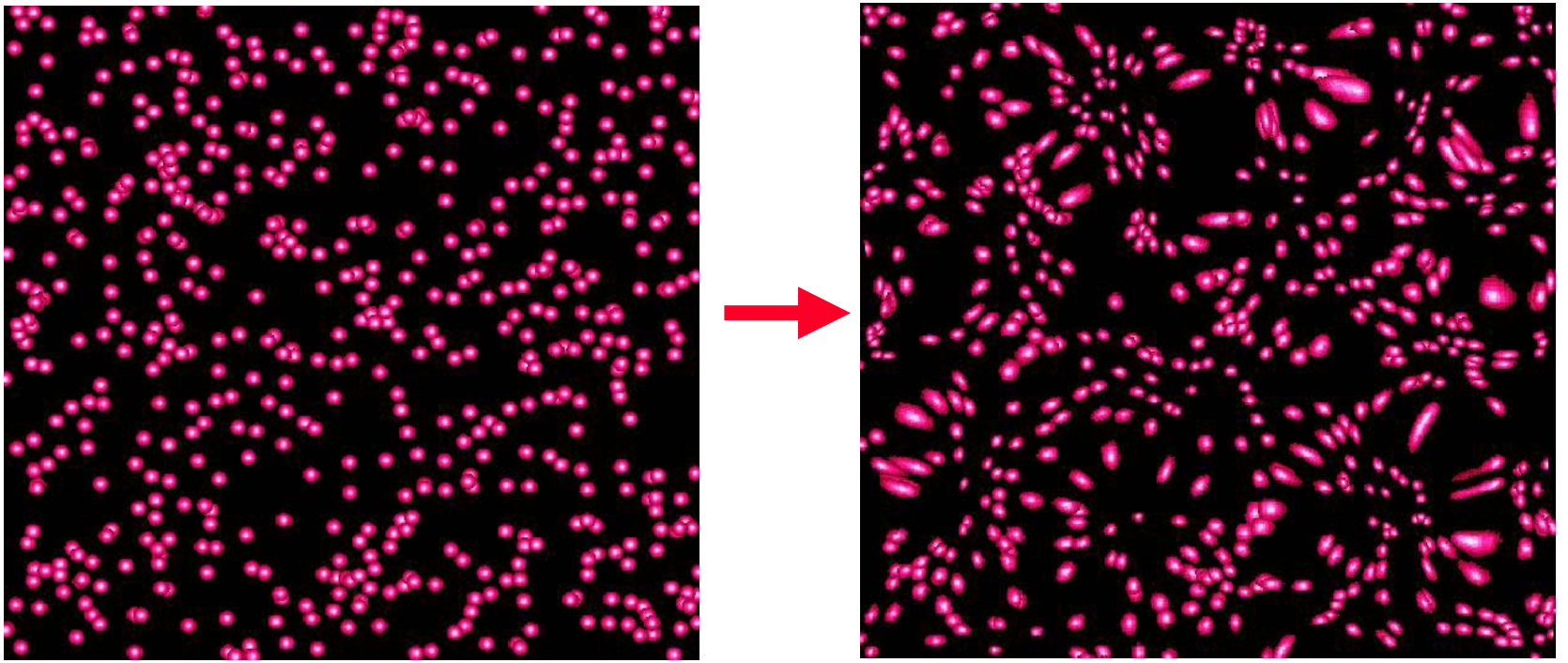
$z_{observer} = 0$

$z_{lens} \approx 1/2$

$z_{source} \approx 1$

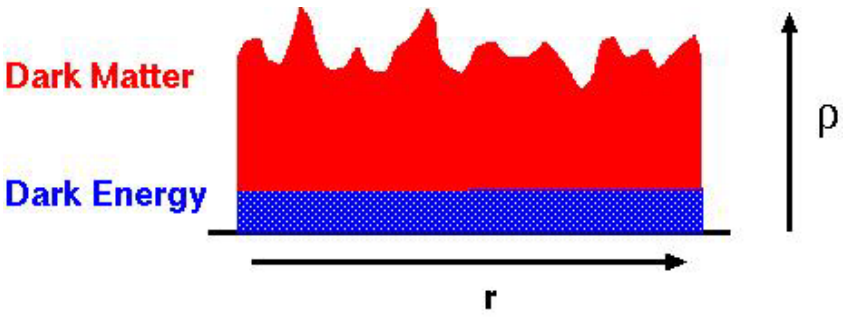
How Gravitational Lensing works

Distortion of background images by foreground matter

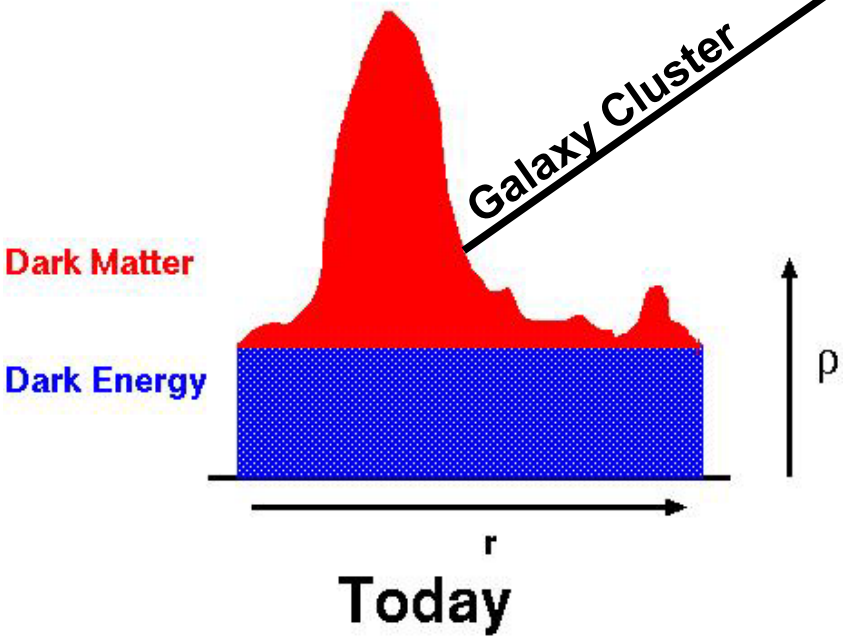


Unlensed **Lensed**

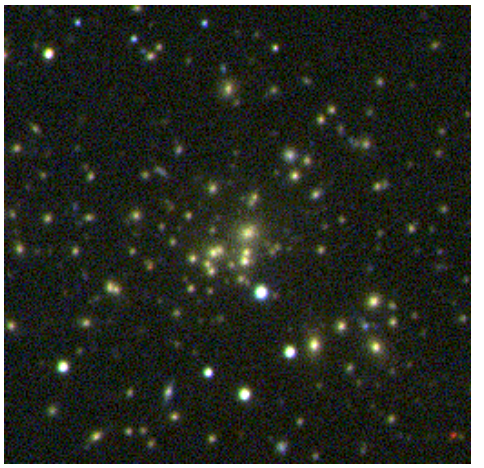
Galaxy Clusters depend on dark energy



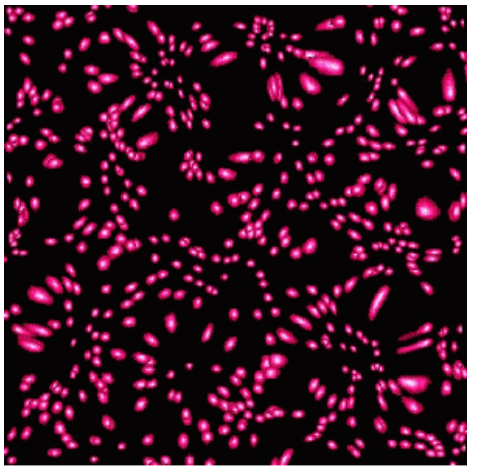
Early Universe



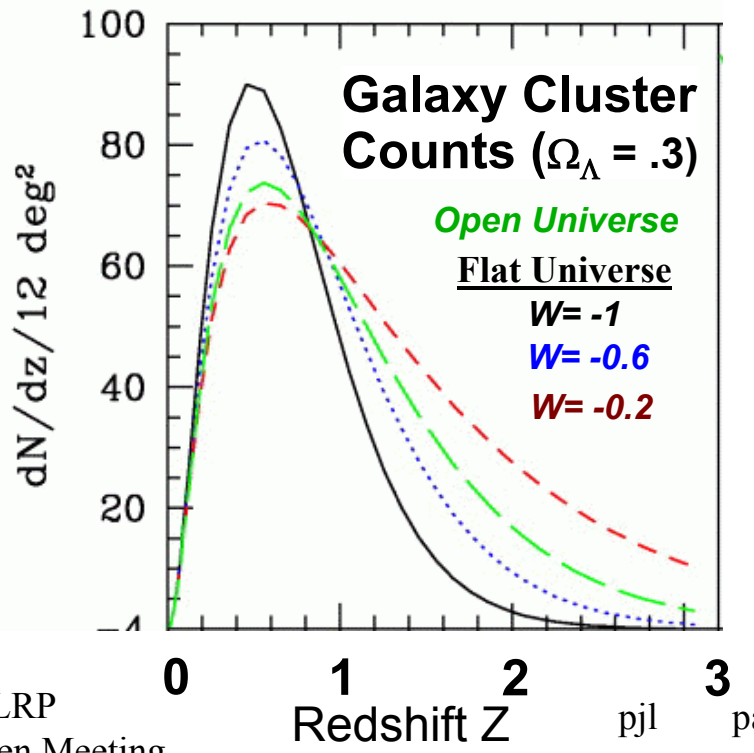
Today

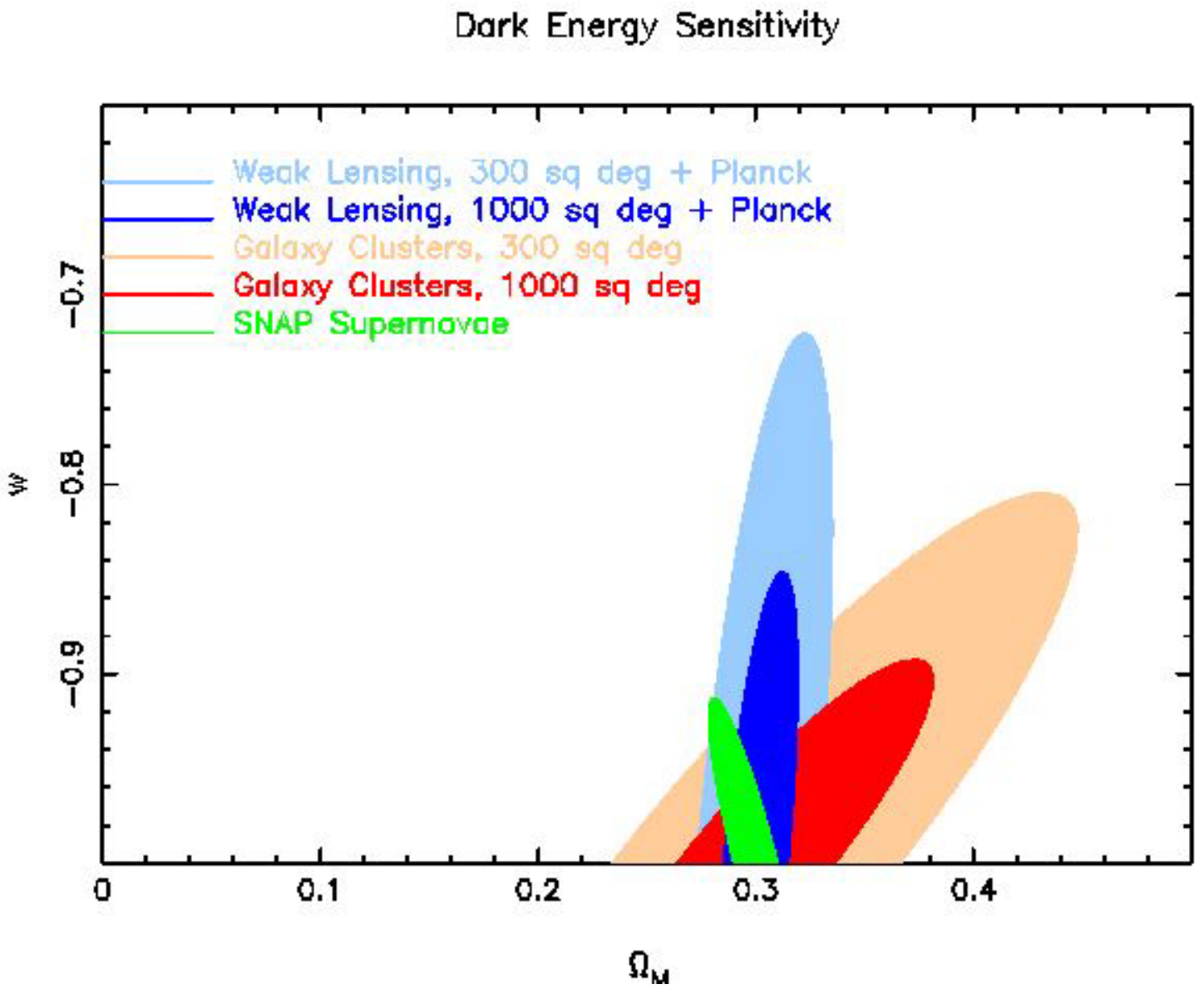


Optical

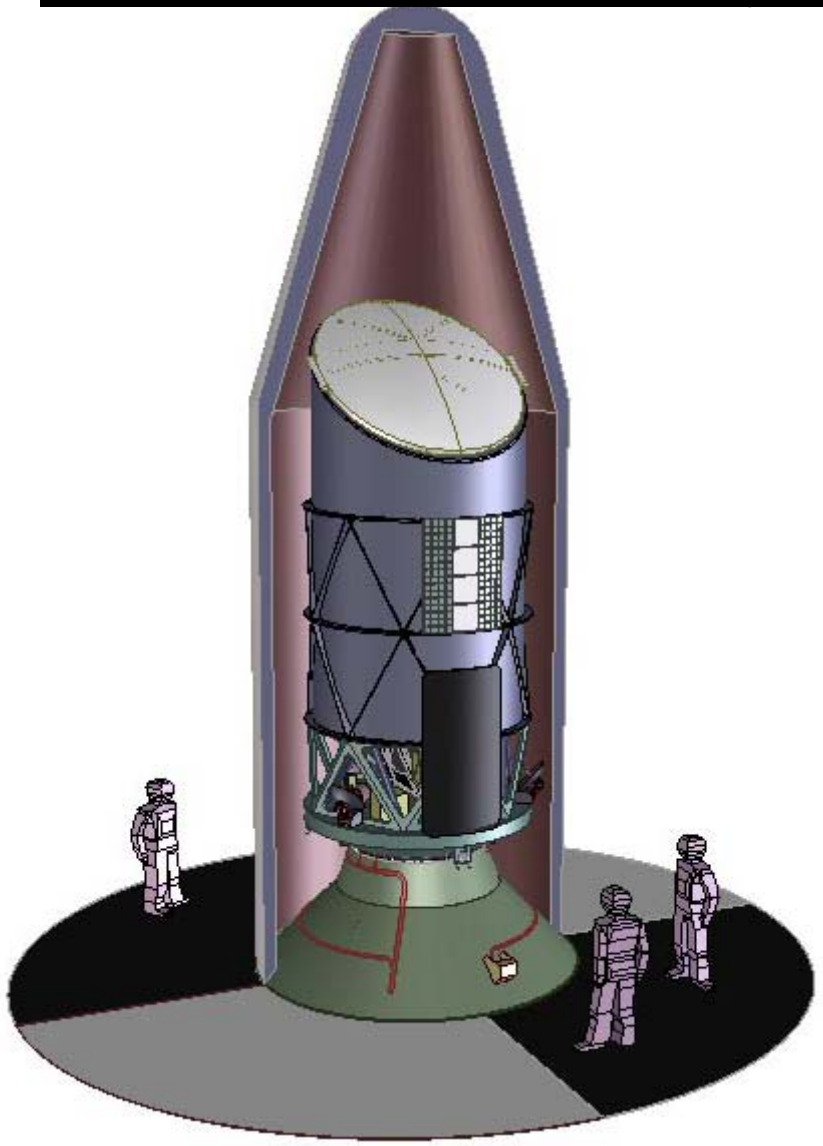


Weak Lensing

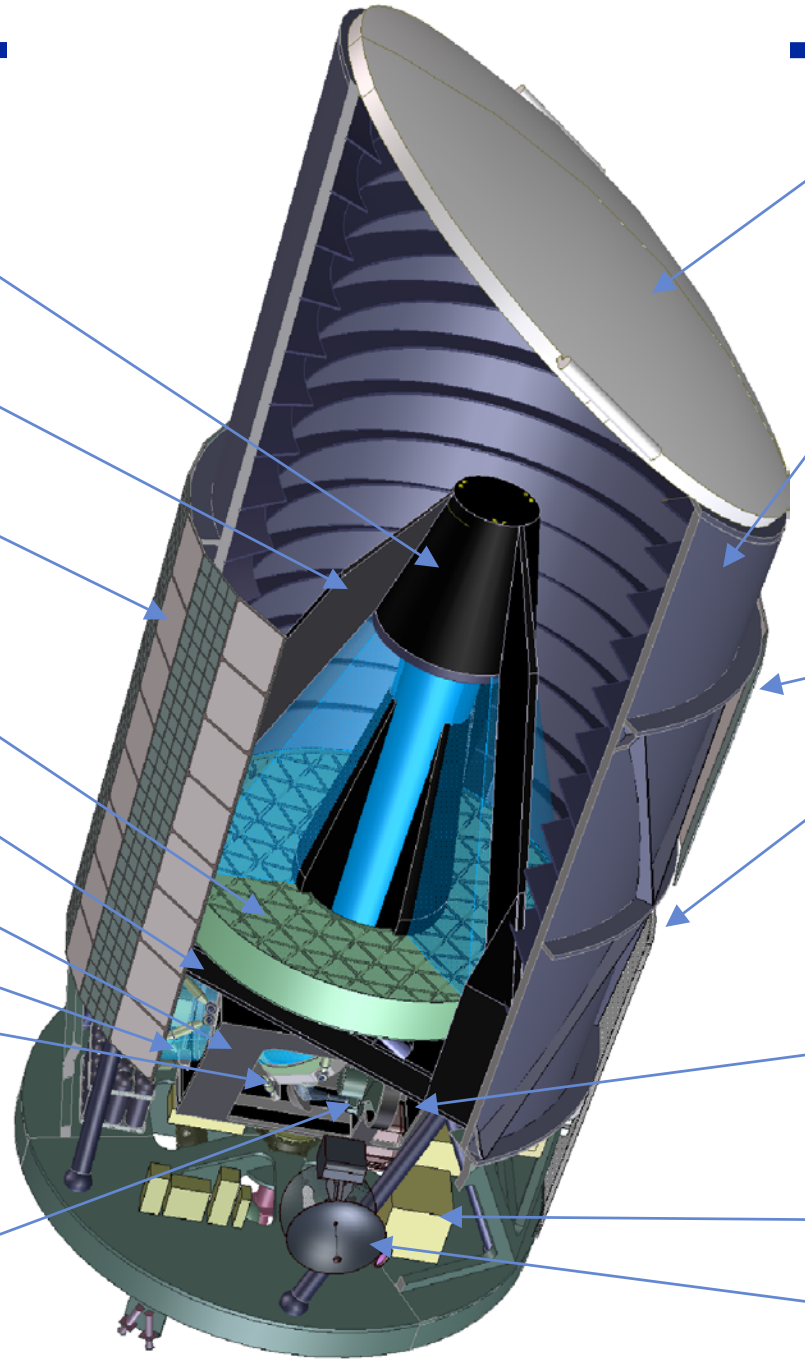



Dark Energy Sensitivity
Weak Lensing, 300 sq deg + Planck
Weak Lensing, 1000 sq deg + Planck
Galaxy Clusters, 300 sq deg
Galaxy Clusters, 1000 sq deg
SNAP Supernovae
w
−0.7
−0.8
−0.9
0
0.1
0.2
0.3
0.4
Ω_M

- **SNAP in a Delta IV-M Payload Bay**



Fermilab



Secondary Mirror
Hexapod
Bonnet

Secondary Metering structure

Solar Array, 'Sun side'

Primary Mirror

Optical Bench

Instrument Metering
Structure

Tertiary Mirror

Fold-Flat Mirror

Spacecraft
- ACS
- CD & H
- Comm
- Power
- Data

Shutter

Door Assembly

Main Baffle Assembly

Solar Array, 'Dark side'

Instrument Radiator

Instrument Bay
- CCD detectors
- NIR detectors
- Spectrograph
- Focal Plane guiders
- Cryo/Particle shield

Solid-state recorders

Hi Gain Antenna

The Supernova/Acceleration Probe (SNAP) Collaboration

G. Aldering, C. Bebek, J. Bercovitz, M. Bester, W. Carithers, E. Commins, C. Day, R. DiGennaro, G. Goldhaber, D. Groom, H. Heetderks, S. Holland, D. Huterer, W. Johnston, A. Karcher, A. Kim, W. Kolbe, B. Krieger, G. Kushner, N. Kuznetsova, J. Lamoureux, R. Lafever, M. Lampton, M. Levi, E. Linder, S. Loken, R. Miquel, P. Nugent, H. Oluseyi, N. Palaio, D. Pankow, S. Perlmutter, N. Roe, M. Sholl, G. Smoot, A. Spadafora, H. von der Lippe, J-P. Walder, G. Wang

Lawrence Berkeley National Laboratory, University of California Berkeley, and University of California Space Sciences Laboratory

C. Akerlovf, B. Bigelow, D. Gerdes, D. Levin, T. McKay, S. McKee, M. Schubnell, G. Tarlé, A. Tomasch

University of Michigan

R. Ellis, J. Rhodes

California Institute of Technology

C. Bower, N. Mostek, J. Musser, S. Mufson

Indiana University

G. Bernstein, L. Gladney, B. Jain, D. Rusin

University of Pennsylvania

A. Fruchter, R. Bohlin

Space Telescope Science Institute

S. Deustua

American Astronomical Society

P. Astier, E. Barrelet, A. Bonissent, A. Ealet, J-F. Genat, R. Malina, R. Pain, E. Prieto, A. Refregier, G. Smadja, D. Vincent

France: IN2P3/INSU/CEA/LAM

R. Amanullah, L. Bergström, M. Eriksson, A. Goobar, E. Mörtsell

University of Stockholm

C. Baltay, W. Emmet, J. Snyder, A. Szymkowiak, D. Rabinowitz, N. Morgan

Yale University

D. Huterer

Case Western Reserve University

R. Massey

Cambridge University

Other Applicants for SNAP Membership

SLAC (Astro Intstitute)

Fermilab

Presently 20 Scientists from all divisions are applying for membership.

Sahar Allam, Jim Annis, Fritz DeJongh, Tom Diehl, Scott Dodelson

Josh Frieman, Lam Hui, Steve Kent, Peter Limon, Huan Lin, John Marriner,

Nikolai Mokhov, John Peoples, Igor Rakhno, Vic Scarpine, Albert Stebbins,

Sergei Striganov, Chris Stoughton, Doug Tucker, William Wester

We expect institutional and individual membership in a few weeks.

Others are interested in joining, but are not yet active.

Present Level of Effort at Fermilab

- **Most Fermilab scientists have signed up for specific responsibilities**
- **About half are members of the Experimental (SDSS) or Theoretical Astrophysics groups. The rest are high-energy physicists.**
- **At the working-group level, there is lots of interactions with SNAP.**
- **We hope to have about 6 to 8 FTE scientists in FY2004.**
  - **We are becoming important members of SNAP.**
- ***This depends on approving nods from the SNAP collaboration, DOE and the Fermilab Director, and possibly on other issues.***

What Will Fermilab Do?

Science Interests

• Many Fermilab scientists are interested in SNe deep survey because of its apparent straight-forward connection to dark energy.

• Fermilab may propose an enlarged wide-field survey as a different look at dark energy and dark matter.

- *We expect to lead a large-scale structure effort within SNAP.*
- *It will provide results with different systematics*
- *An enlarged wide-field survey may require some minor mission modifications*

Our Internal Criteria for Work

• Fermilab's work must be useful to SNAP

• Fermilab should have special expertise in the required scientific skills and/or technology **OR** the task should require national lab capability.

• Preference given to tasks associated with Fermilab science goals for SNAP

Fermilab Proposed Organization & Work Scope

- **Overall Leaders** — *Steve Kent & Peter Limon*
  - **Science & Simulations** — *Albert Stebbins*
  - **Photometric Calibration** — *Steve Kent*
    - *Expertise due to SDSS work*
  - **Scientific Software & Archiving** — *Chris Stoughton*
    - *Expertise due to SDSS work*
  - **Electronics** — *John Marriner*
    - *Solid-state recorder*
    - *Data compression hardware*
      - Both of above could help wide-field survey
    - *Electronics associated with the focal plane*
    - *Microwave systems for telemetry*
  - **Radiation Shields** — *Tom Diehl*
    - *Cosmic-ray, light baffle, thermal*
    - *Involved in all three; concentrate on cosmic-ray shield and integration*
      - Uses GEANT & MARS design tools
      - Serious mechanical & thermal engineering requires solid modeling and sophisticated FEA

Electronics

Fermilab's proposal to enlarge the wide-field survey may affect some aspects of the mission, in particular, creating a larger data set. Fermilab proposes to work on electronics that will help mediate those issues.

- **The data storage system**
  - **A solid state recorder to store more data on board**
  - **Improved data compression hardware to reduce the size of stored data set for the wide-area survey**
  - **Possibly other systems & integration issues**
- **Fermilab has expertise in areas that may be useful to the mission. Not yet clear whether we will work on these items.**
  - **Electronics associated with the focal plane**
    - *Fermilab has extensive ASICs expertise.*
    - *Other electronics (control, monitoring, etc.)*
  - **Microwave systems for data telemetry on the ground and possibly on the space vehicle.**
    - *Fermilab has expertise in microwaves gained through accelerator technology.*

Cosmic Ray Shield

Fermilab proposes to take leadership responsibility for the cosmic-ray shield and its integration into the instrument, the other shields and the spacecraft.

Purpose of the cosmic ray shield

- **Reduce the cosmic ray background during the ~300 s to 500 s exposures.**
- **Reduce the radiation damage to the detector elements and the electronics from cosmic rays, solar wind and Van Allen belt radiation.**

Scope of Work

- **Fermilab will contribute to the design, and possibly the fabrication of all the shields**
  - **Primary responsibility for the design and integration of the cosmic ray shield. Whether fabrication is involved is not known at this time.**
  - **Physics design involves understanding the cosmic ray flux in the SNAP orbit, simulating its effects on the detector, the electronics and signal -to-noise using GEANT and MARS, and optimizing the shield design for reduction of the flux and spacecraft weight**
  - **Engineering design takes the requirements of the physics design and optimizes the cosmic ray shield for mechanical stability, cost, integration into the spacecraft, the instrument and other shields, etc.**

Why Should Fermilab Join SNAP?

- **If we're in we get to participate in important science.**
  - o *We bring our own science ideas to SNAP – ideas that make SNAP a better mission.*
  - o *Fermilab's participation strengthens the connection between astrophysics and particle physics.*
- **Fermilab's presence makes the mission stronger and more likely to succeed.**
  - o *We are a large group with the scientific, technical and organizational strengths typical of a DOE laboratory.*
  - o *Fermilab's SNAP group is very strong in astronomy, something SNAP needs, with excellent experimental and theoretical astrophysics groups.*
- **Participation in SNAP will strengthen Fermilab scientifically and technically.**
  - o *It helps diversify the Lab in a field that is intimately connected to particle physics.*
  - o *SNAP is a challenging mission that will stretch our technical and engineering capabilities.*

Why Should Fermilab Join SNAP?

- **From the Report from HEPAP to the DOE Office of Science concerning U.S. HEP Facilities.**
- **Three proposed facilities were considered "*Absolutely Central*":**
  - **A Linear Collider**
  - **An LHC Luminosity Upgrade**
  - **SNAP**